10-Wiring Practices

Text: Chapter 9.4

ECEGR 3500

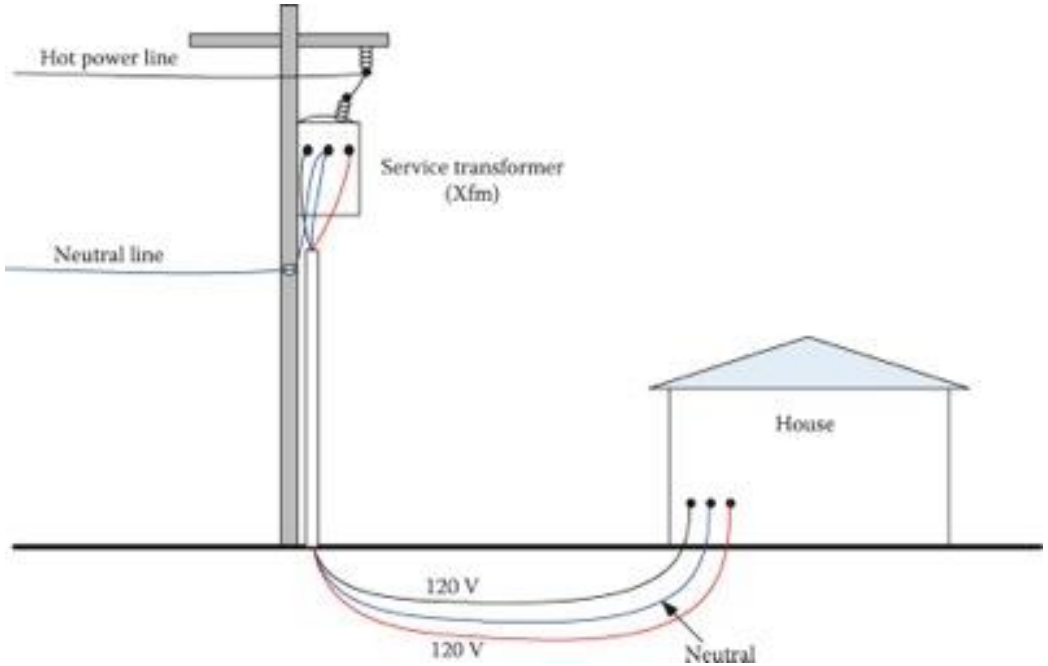
Electrical Energy Systems

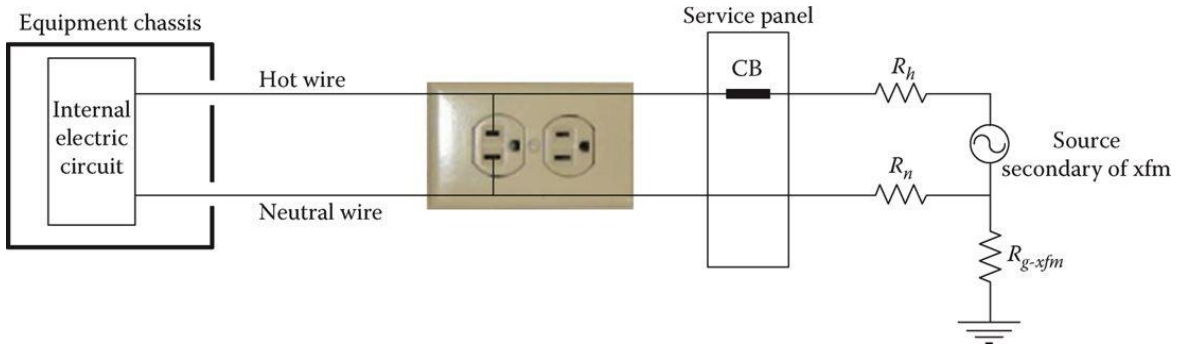
Professor Henry Louie

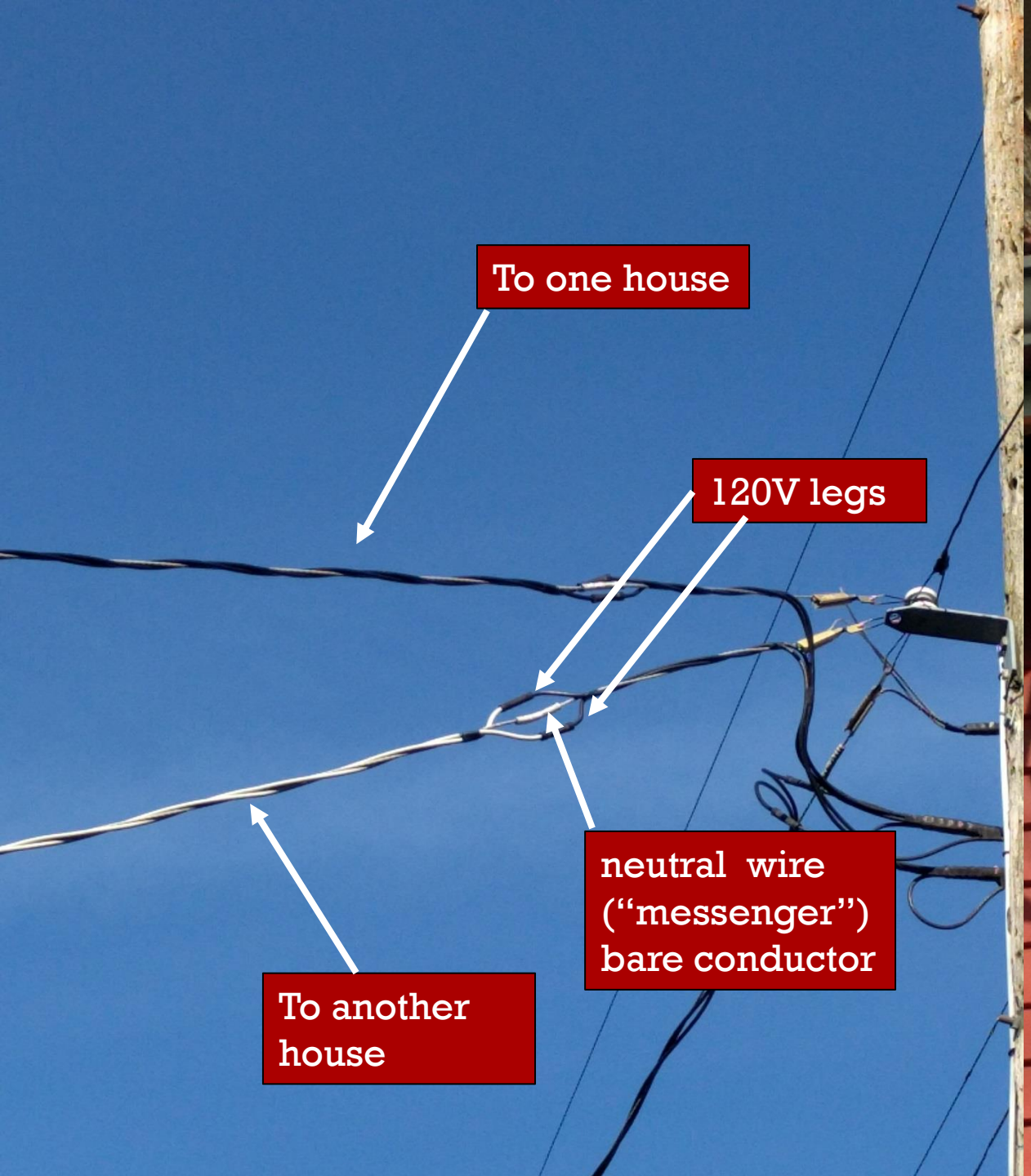
Overview

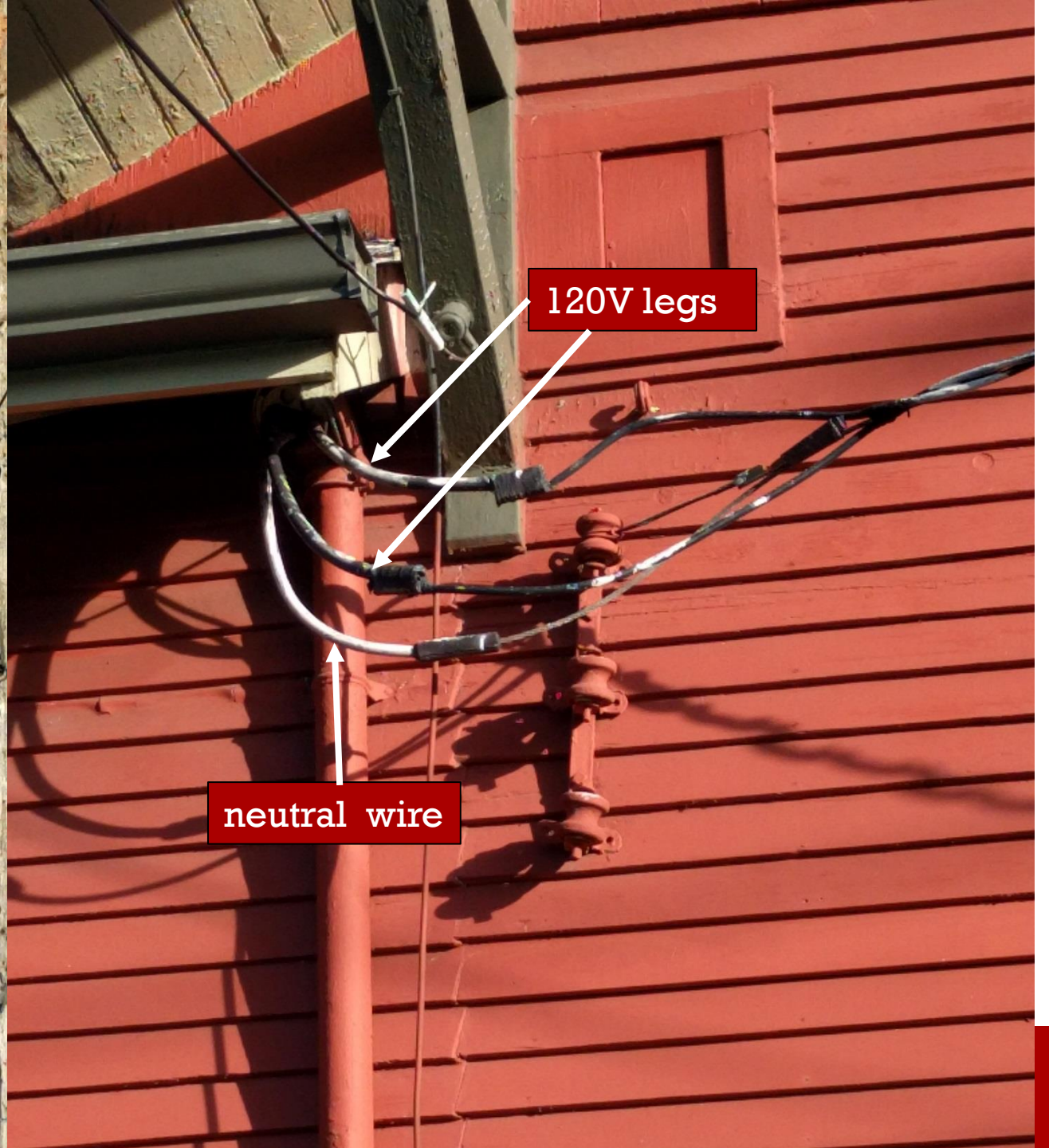
- Typical Residential Electricity Service
- Neutral vs. Ground
- Ground Fault Circuit Interrupter

Typical Residential Electricity Service



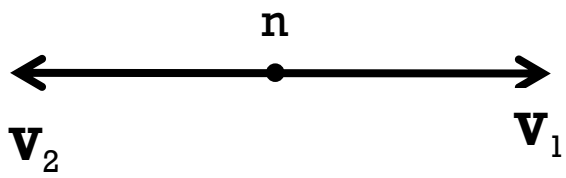



To one house
120V legs
neutral wire
("messenger")
bare conductor
To another
house


120V legs
neutral wire

Typical Residential Electricity Service

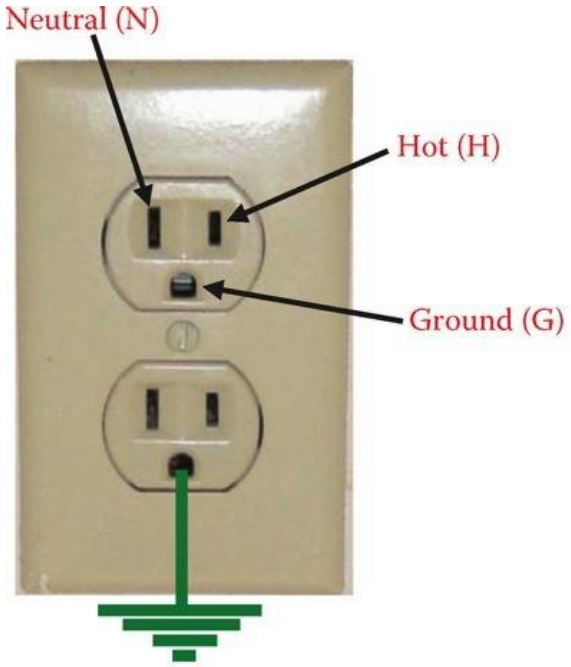
- The service transformer is center tapped, which provides two 120V phases, that are 180 degrees out of phase
- The voltage $\mathbf{V}_{1n}$ and $\mathbf{V}_{2n}$ is 120V
- The voltage from $\mathbf{V}_1$ to $\mathbf{V}_2$ is 240, and is used to serve high power loads, such as dryers



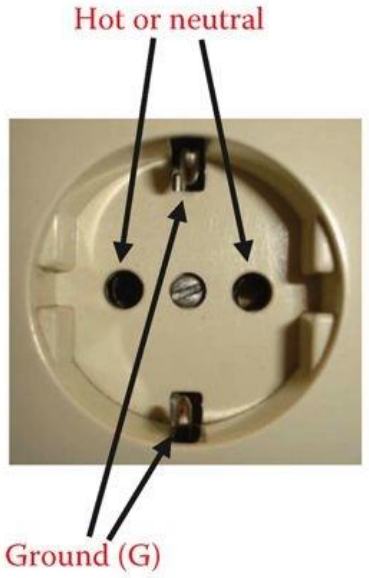
Neutral and Ground

- Under normal operation (which in a home is not assumed to be balanced), the neutral carries return current and the ground does not
- Ground and neutral are connected at the service transformer, and the entrance of the residence
- The purpose of the ground wire is for protection, the purpose of the neutral is provide a path back to the source

Neutral and Ground



Type 1: Most of America



Type 2: Most of Europe

Type 3: England, parts of the Middle - East and Asia

Neutral and Ground

(a)

(b)

(c)

Why do some plugs have a ground prong, and others do not?

What could go wrong?

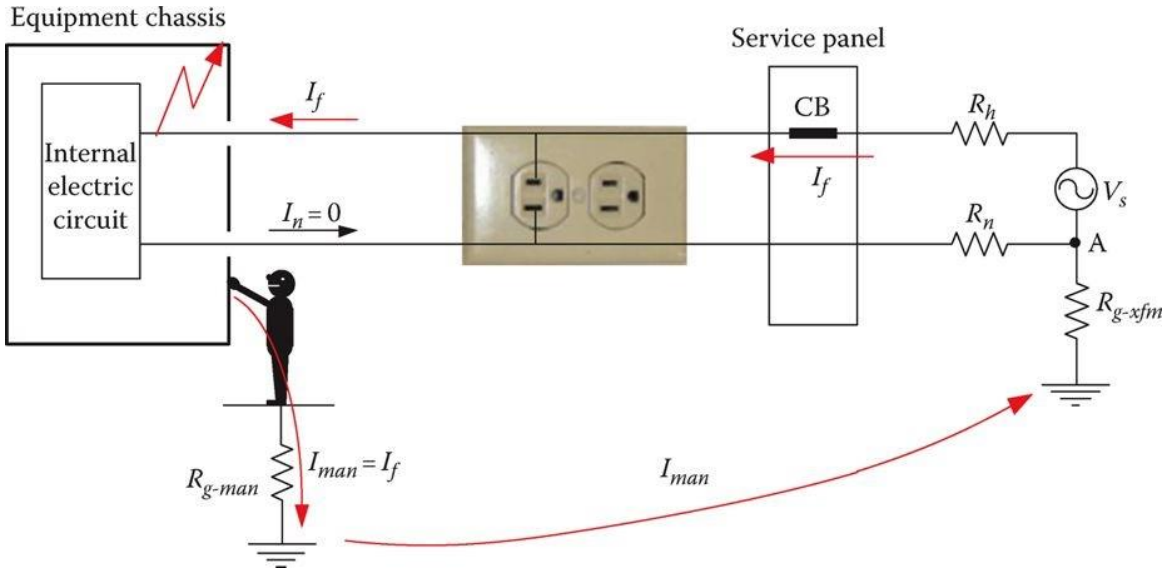
What happens if the "hot" wire touches the case of the metallic washing machine?

What could go wrong?

- If the washing machine is connected only by the hot wire and neutral, the washing machine's case becomes energized (at or near 120V)
- This is a hazardous condition
- What happens if someone touches the washing machine?

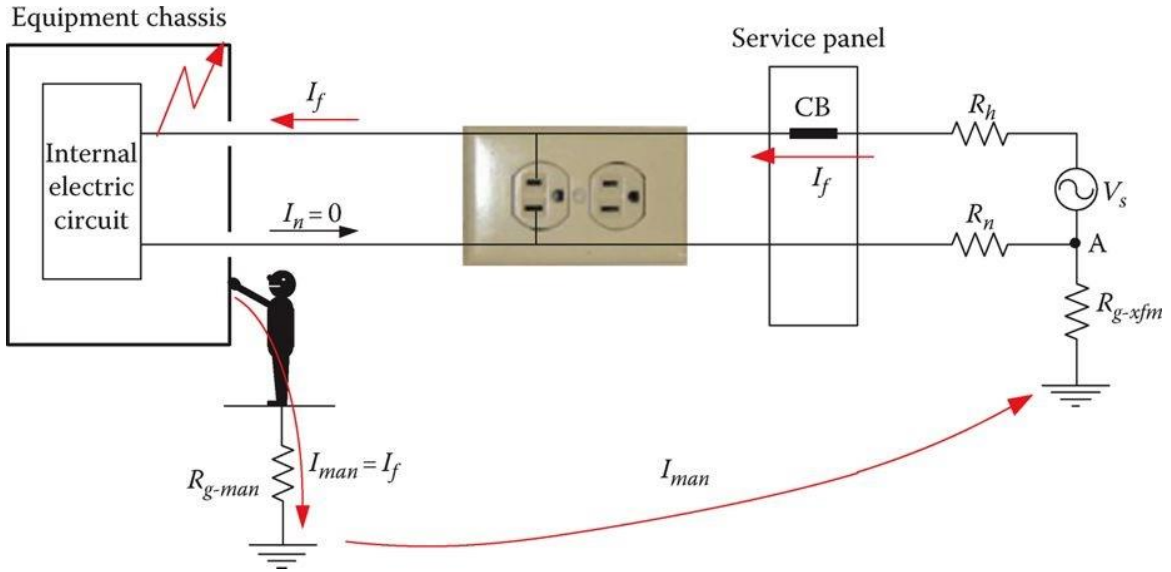
What could go wrong?

- If the person is grounded, current will flow through them and they could be harmed



Exercise (Example 9.9)

Assume that the circuit breaker is rated 20 A, the source voltage is 120 V, $R_n = R_h = 0.5\ \Omega$, $R_{g\text{-}man} = 500\ \Omega$, $R_{man} = 1000\ \Omega$, and $R_{g\text{-}xfm} = 20\ \Omega$. Compute the current through the person touching the chassis.



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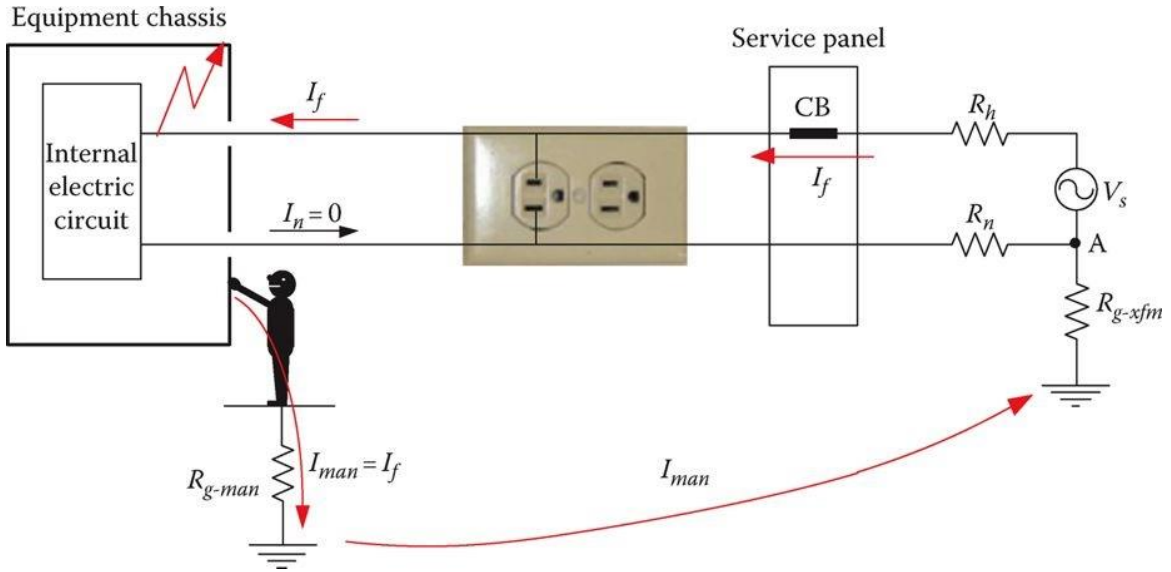
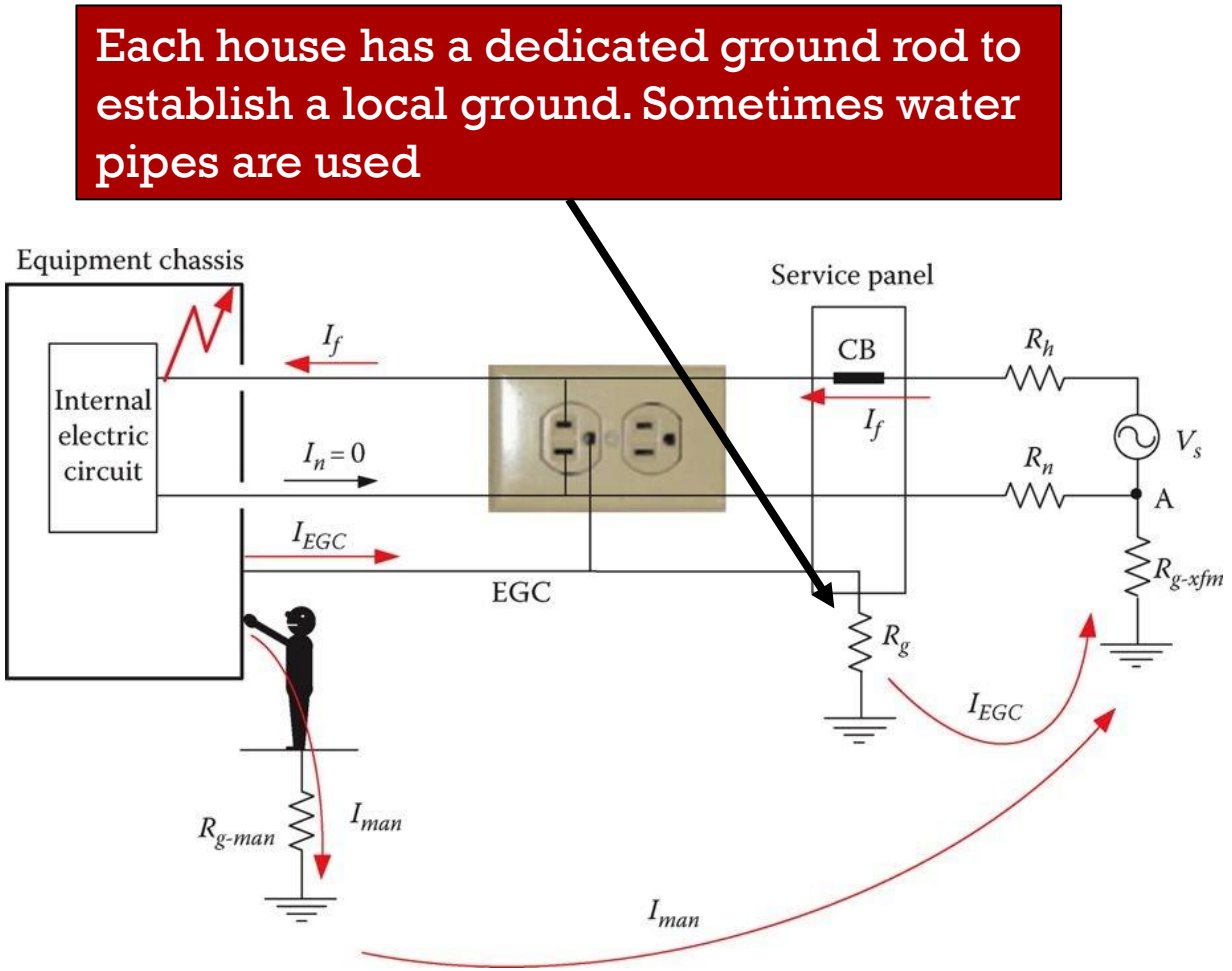
$$I_{man} = I_f = \frac{V_s}{R_h + R_{man} + R_{g,man} + R_{g,xfmr}} = 78.92\text{mA}$$

This can cause death.



Grounded Chassis

- Let's see what happens if we use a three prong plug and connect the chassis to ground
- Equipment Grounding Conductor (EGC): connection between the device and the ground



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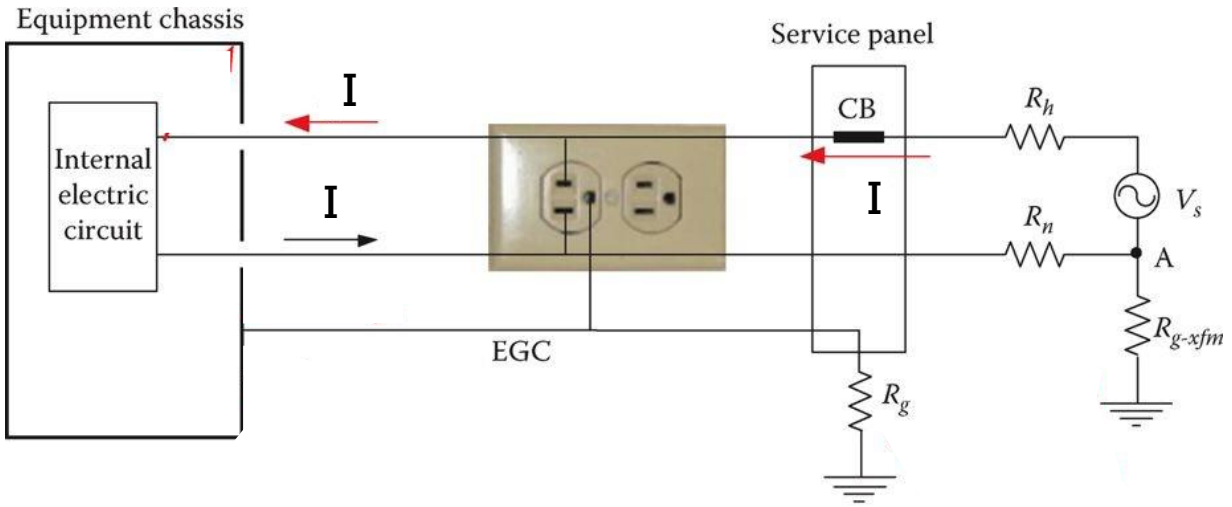
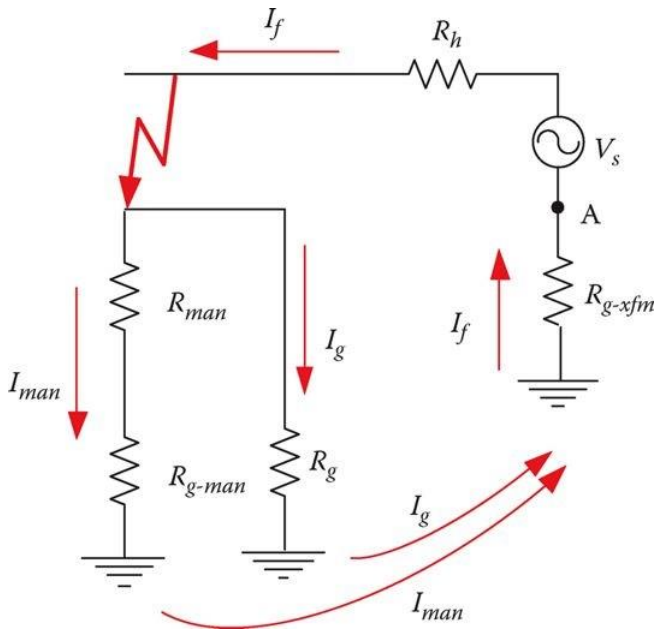
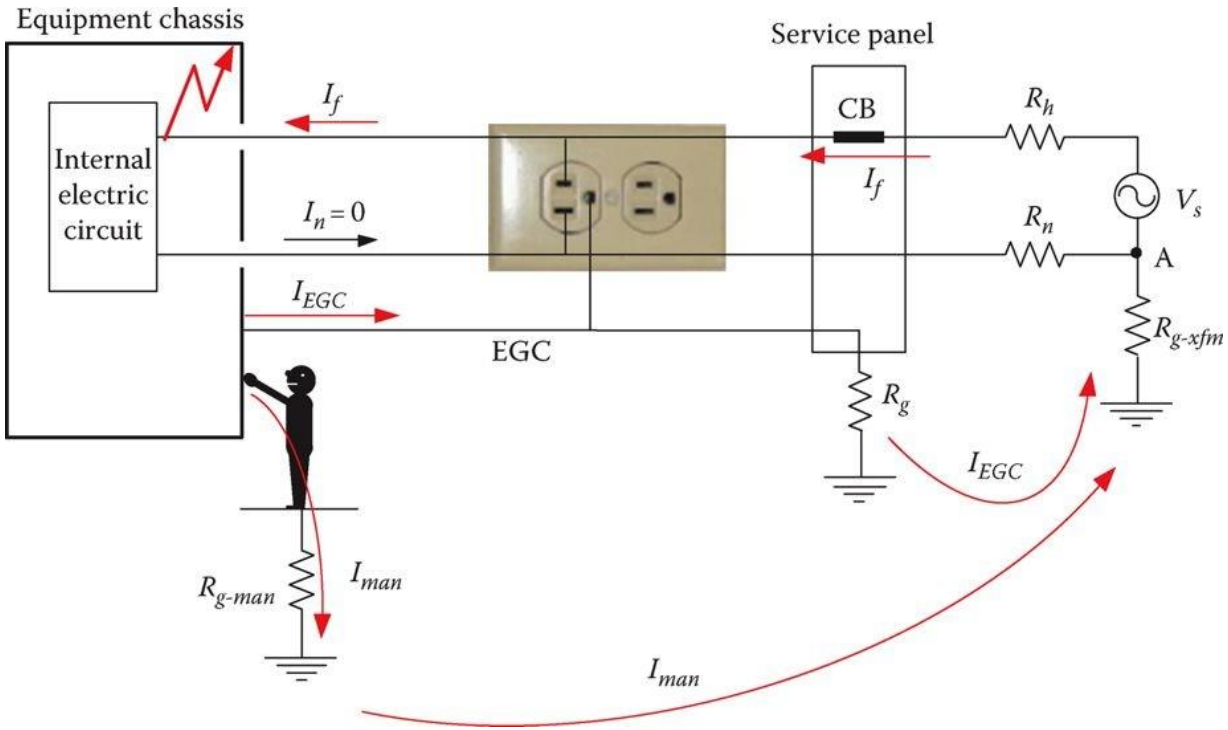


Ground rod buried near service panel

Grounded Chassis

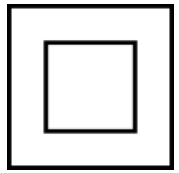
- In this situation, there is a current divider (through the person and through the EGC)





Why do some plugs have three prongs and others just two?

- Usually if the appliance has a metal chassis, it will have three prongs (hot, neutral, ground)
- Several exceptions to this
  - Double insulated (Class II electrical appliance)



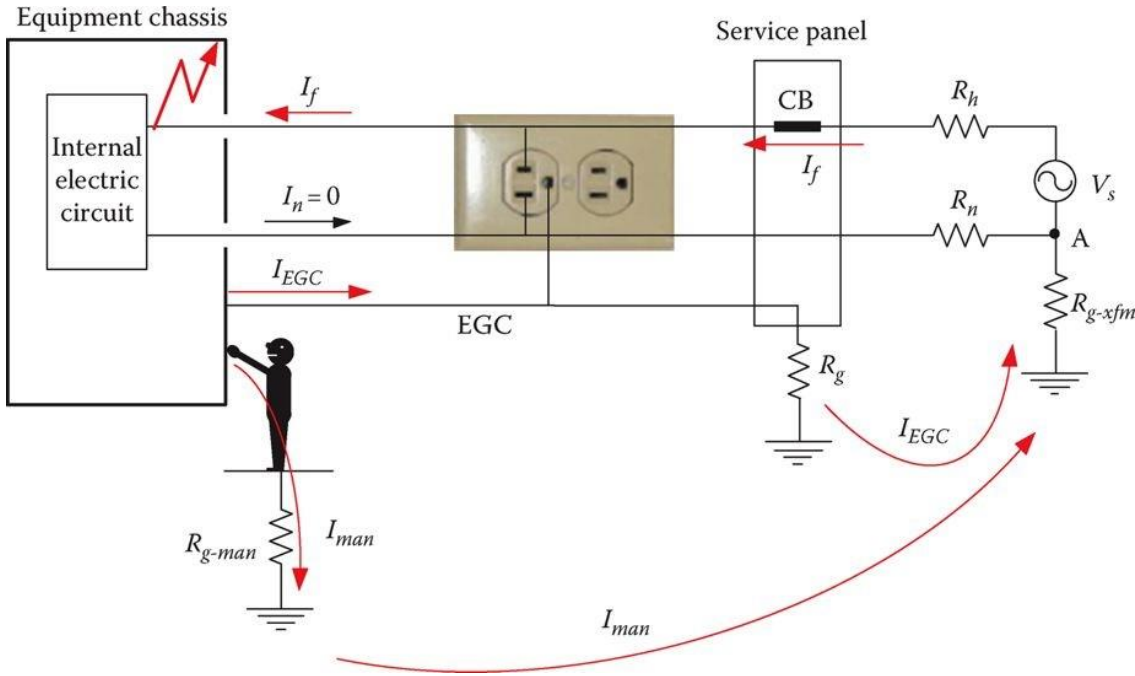
  - Appliances with exposed elements such as a toaster (if a person puts a fork in the toaster and is holding the chassis, a HIGH impedance path to ground is desired, not a low impedance path)
  - Certain appliances like desk lamps have been exempted in various editions of code

Exercise (Example 9.10)

Now assume that the circuit breaker is rated 20 A, the source voltage is 120 V. The system parameters are $R_n = R_h = 0.5\ \Omega$, $R_{g\text{-}man} = 500\ \Omega$, $R_{man} = 1000\ \Omega$, $R_g = 10\ \Omega$, and $R_{g\text{-}xfm} = 20\ \Omega$. Compute the fault current and the current through the person touching the chassis.

Resistance of the man and ground is 1500Ω
The equivalent resistance including EGC is

$$R_{eq} = \frac{R_g 1500}{R_g + 1500} = 9.93\Omega$$



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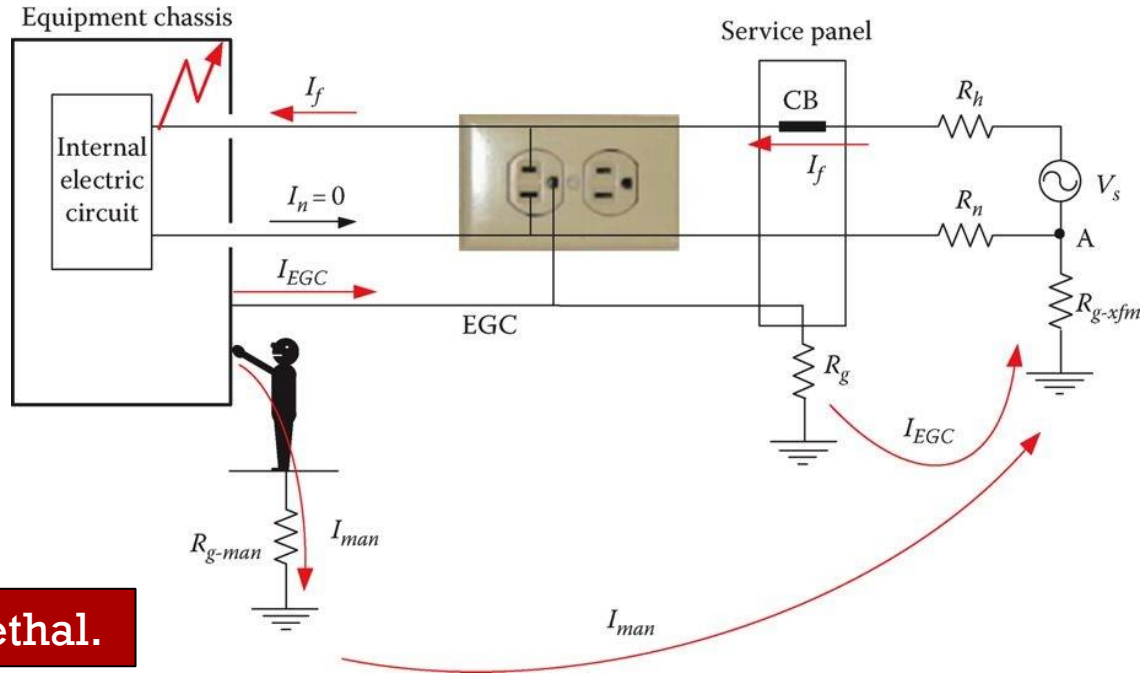
The fault current is:

$$I_f = \frac{V_s}{R_h + R_{eq} + R_{g,xfmr}} = 3.94\text{A}$$

This is divided between the man and EGC. By current divider

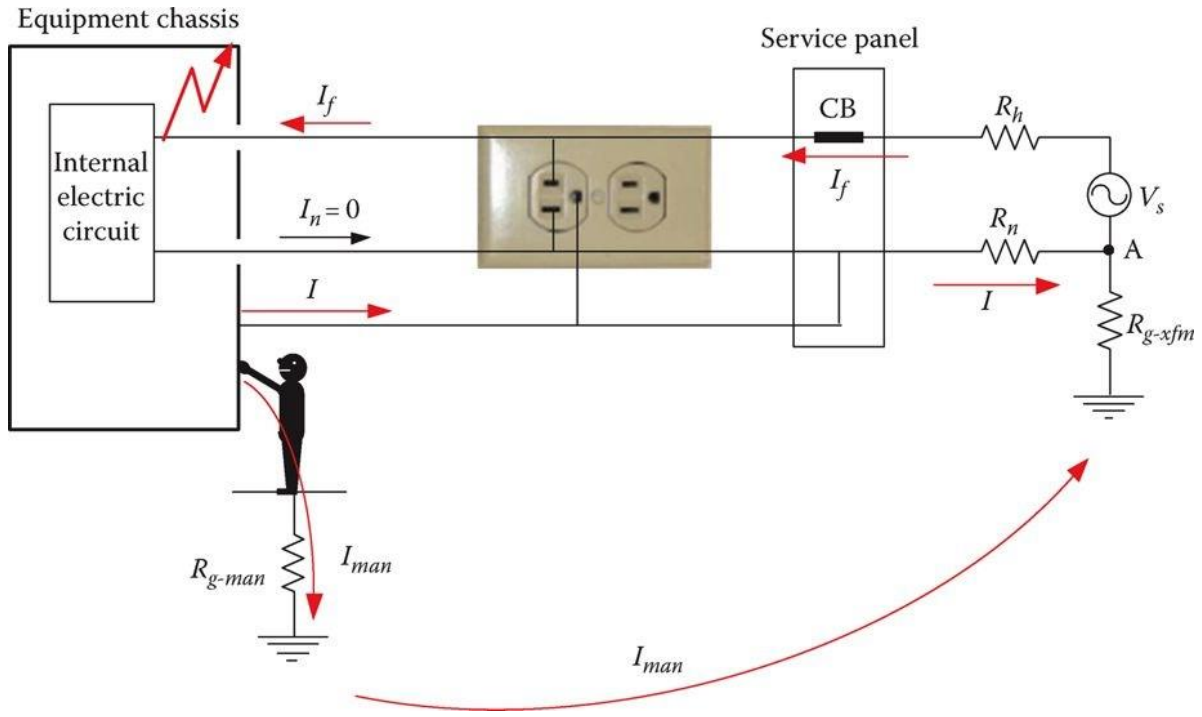
$$I_{man} = I_f \frac{R_g}{R_g + (R_{man} + R_{g,man})} = 26.1\text{mA}$$

This is lower than the last example, but still can be lethal.



Bonded Neutral

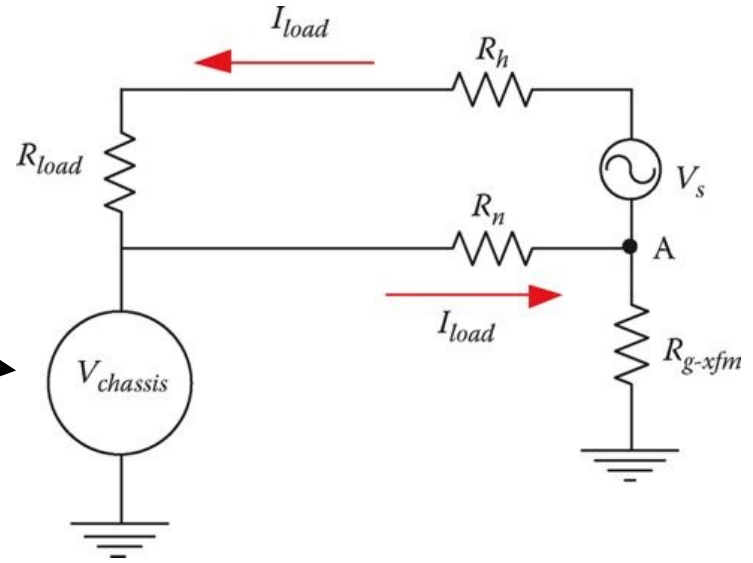
- Now examine what happens if the neutral is bonded to ground, and there is no local ground



The situation is improved because R_n is generally much smaller than $R_{gman} + R_{gxfmr}$. There is a low resistance path back to the source, so a large current flows. The circuit breaker should trip.

Bonded Neutral

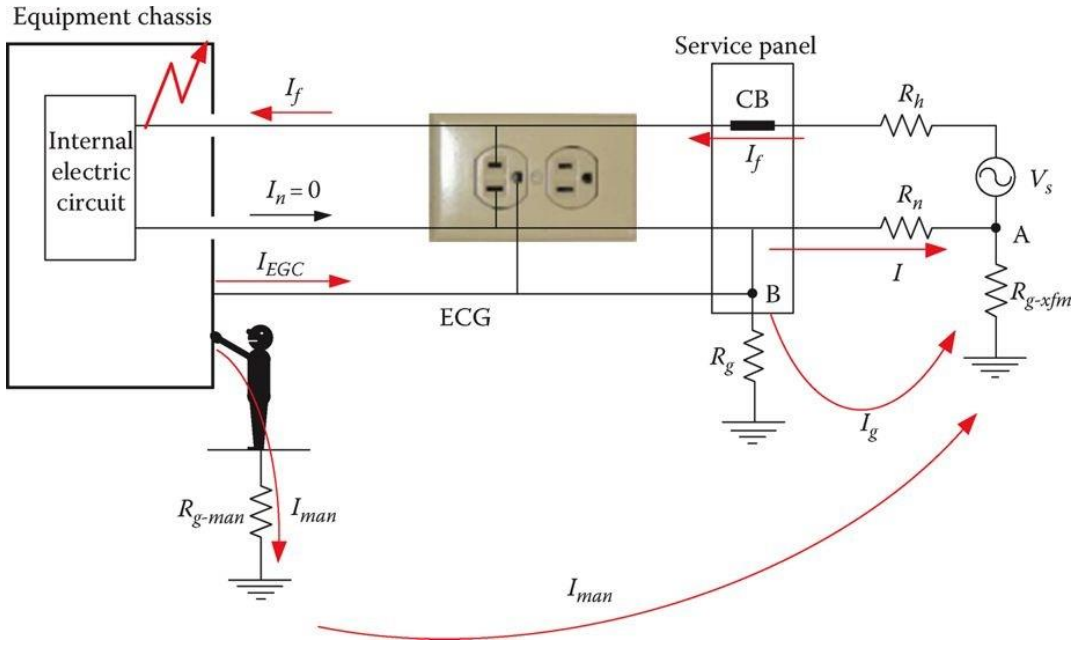
- What happens when large current is drawn by a heavy load?
- A voltage develops between the chassis and ground



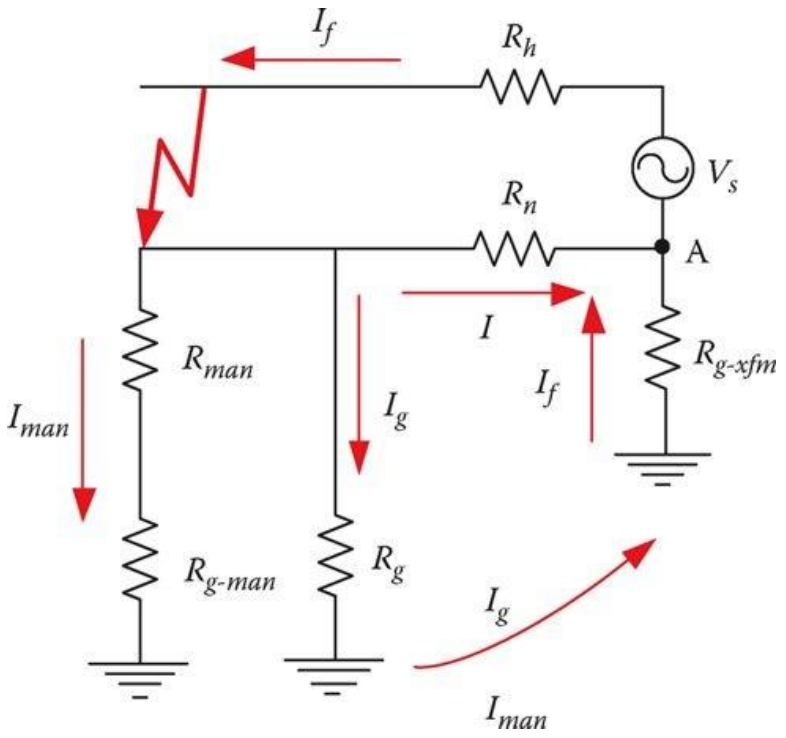
Voltmeter could read a large value due to voltage across R_n

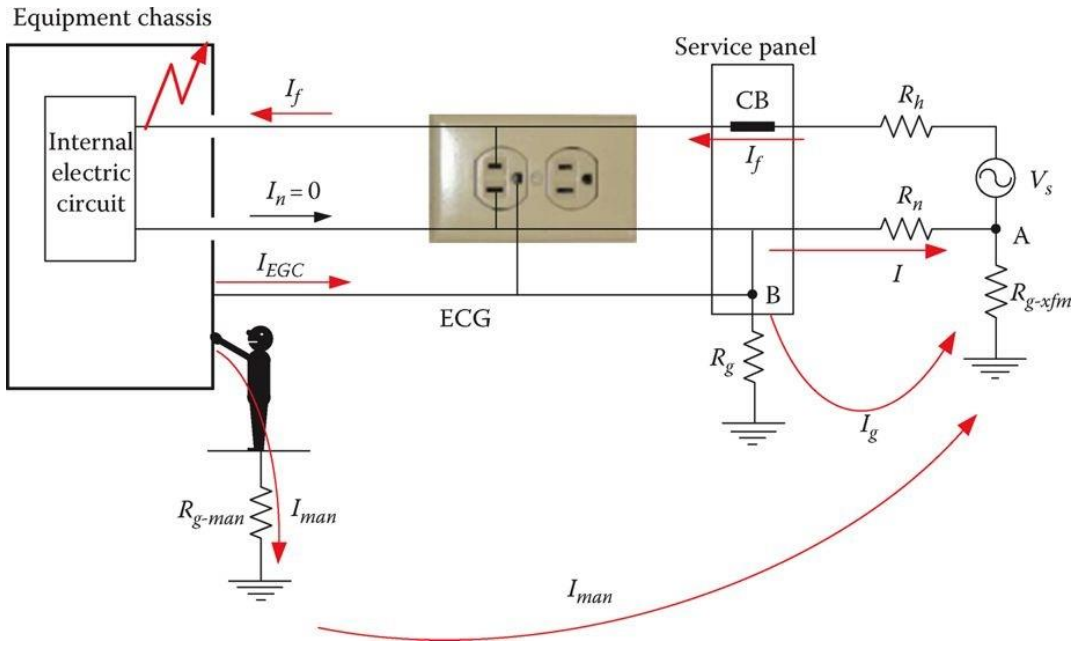
A better way

- Bond the neutral to ground AND provide a local ground
- Advantages:
  - High current will flow, tripping circuit breaker
  - Very little current would flow through the person



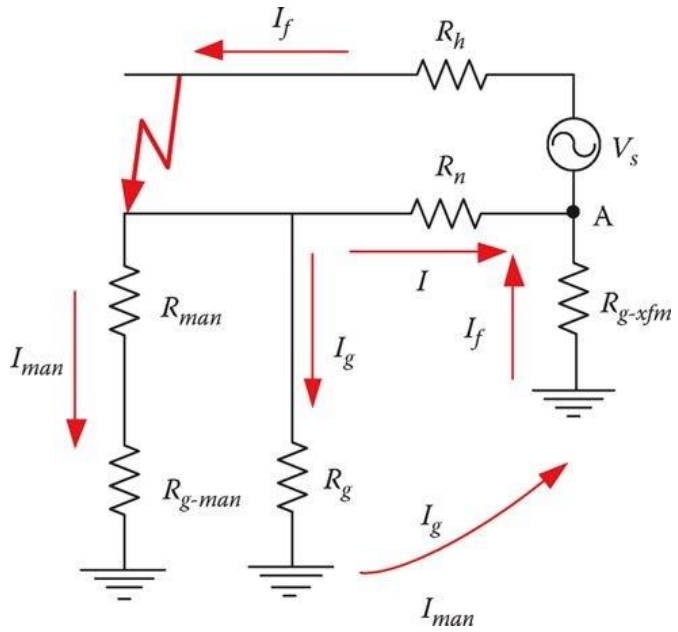
A better way…bond neutral and ground chassis

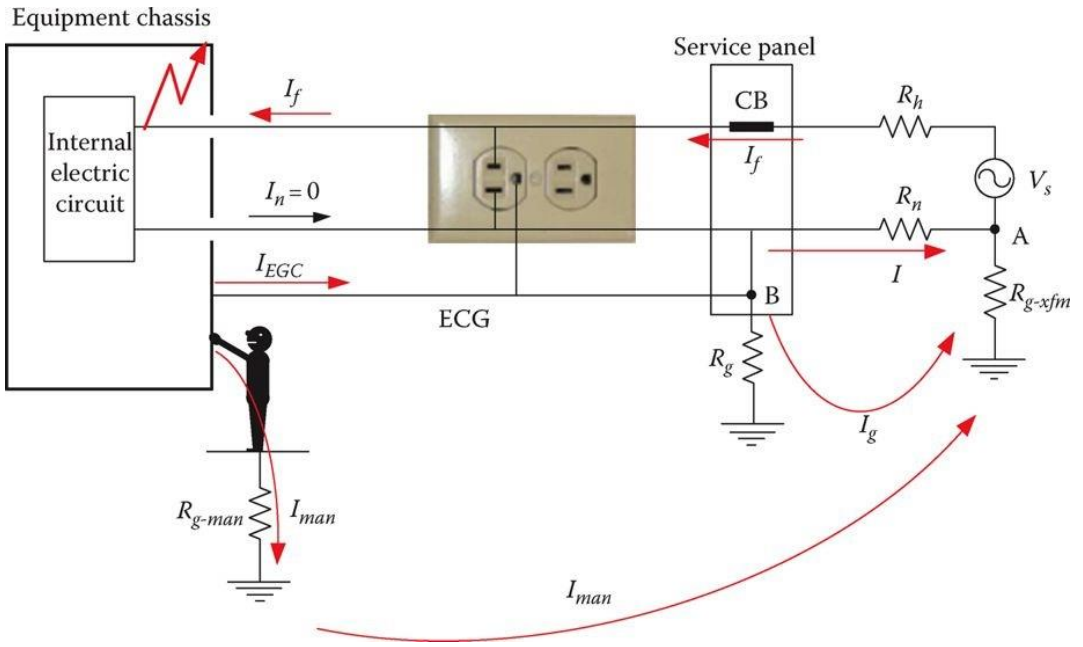




Exercise (Example 9.13)

Now assume that the circuit breaker is rated at 20 A and the source voltage is 120 V. The system parameters are $R_n = R_h = 0.5\ \Omega$, $R_{g\text{-}man} = 500\ \Omega$, $R_{man} = 1000\ \Omega$, $R_g = 10\ \Omega$, and $R_{g\text{-}xfm} = 20\ \Omega$. Compute the fault current.

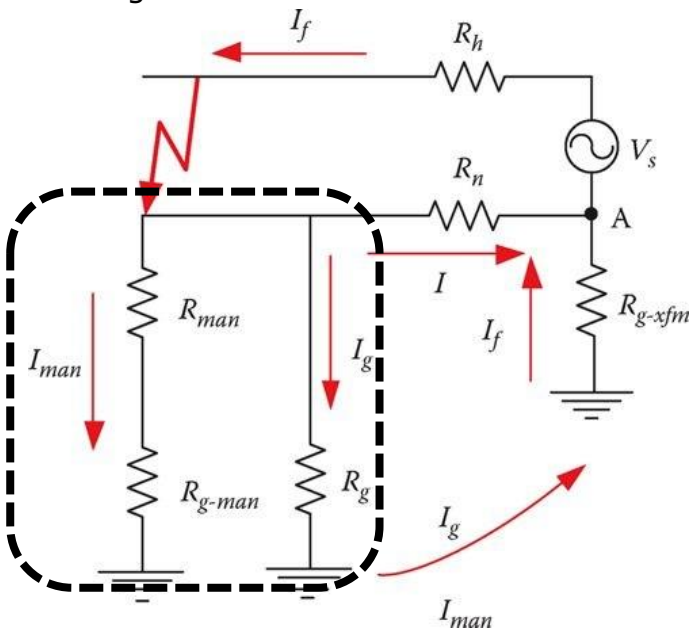


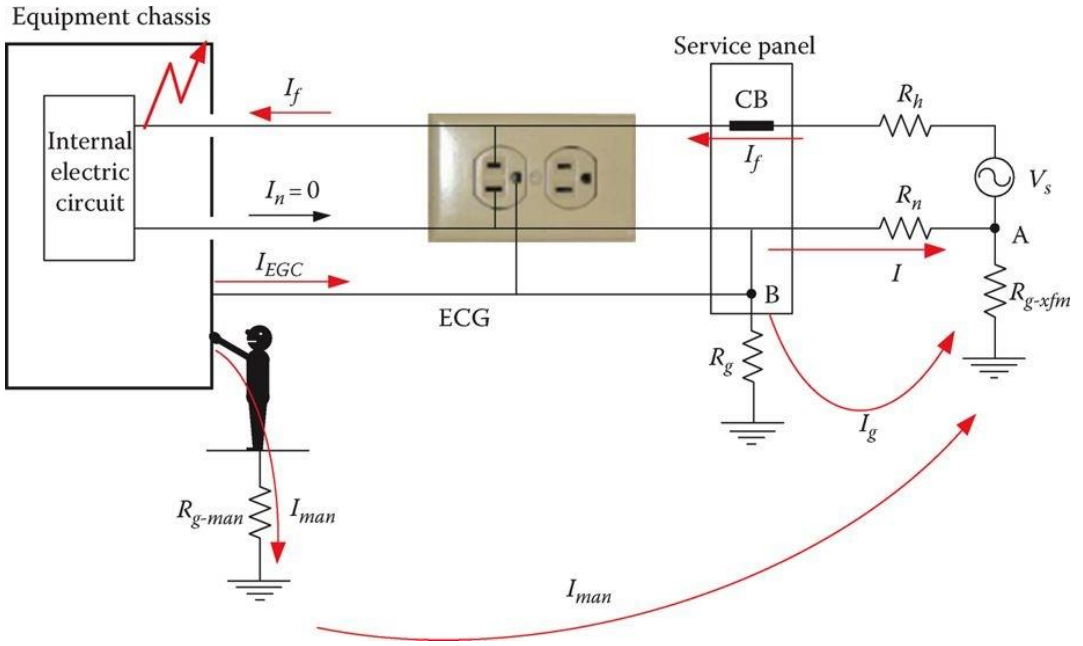


Exercise (Example 9.13)

From before, the resistance of the man and ground is 1500Ω. The equivalent resistance including EGC is

$$R_{eq1} = \frac{R_g 1500}{R_g + 1500} = 9.93\Omega$$

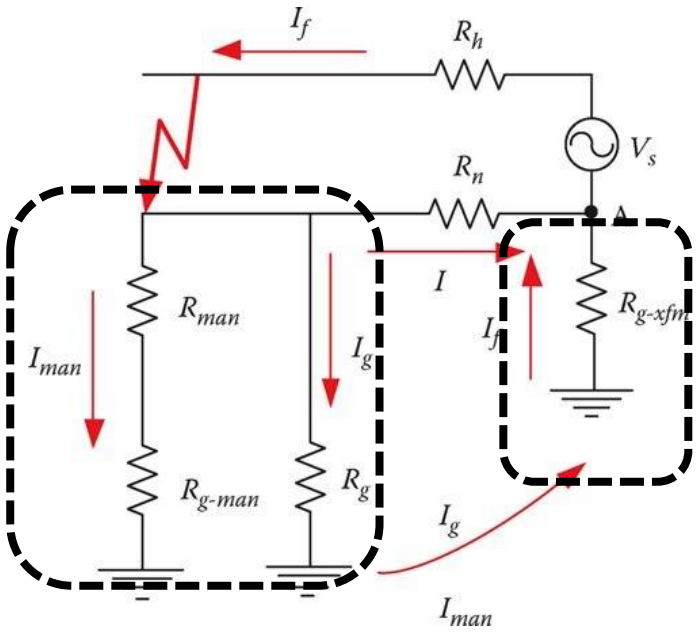


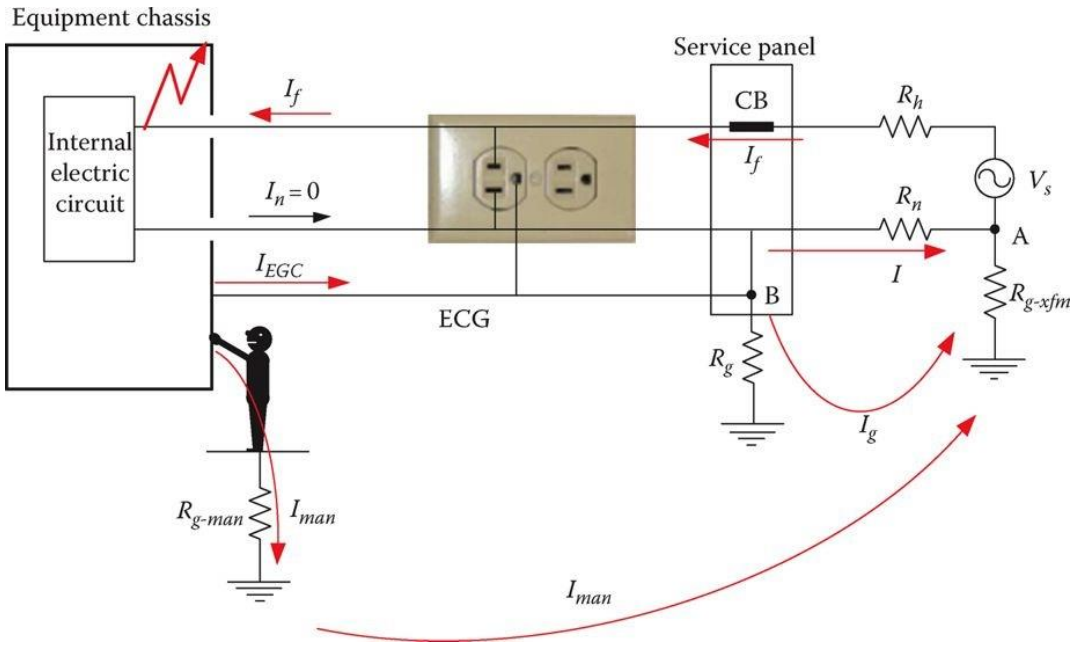


Exercise (Example 9.13)

R_{eq1} is in series with $R_{g,xfmr}$

$$R_{eq2} = 29.93\Omega$$

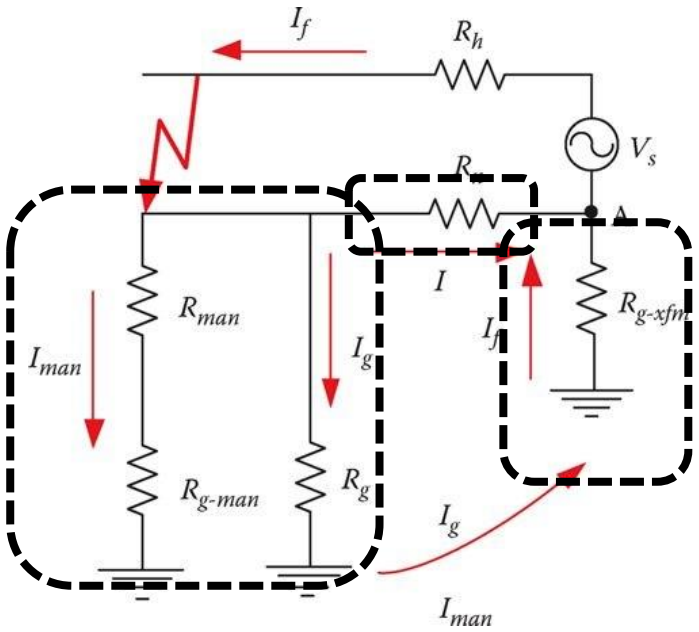


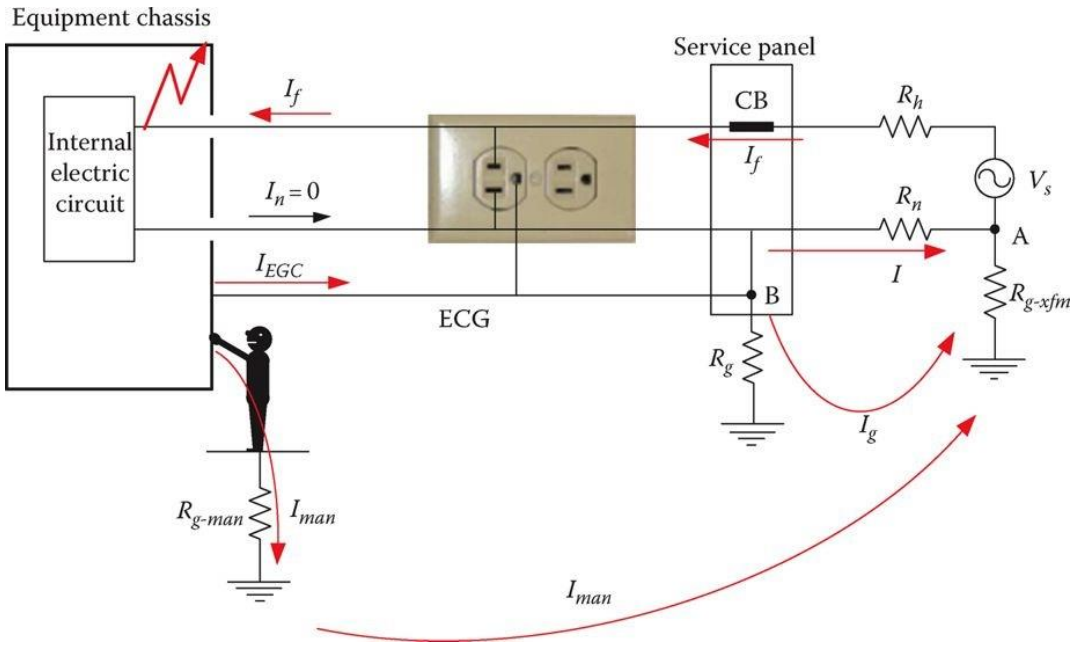


Exercise (Example 9.13)

R_{eq2} is in parallel with R_n

$$R_{eq} = R_n \,||\, R_{eq2} = 0.492\Omega$$



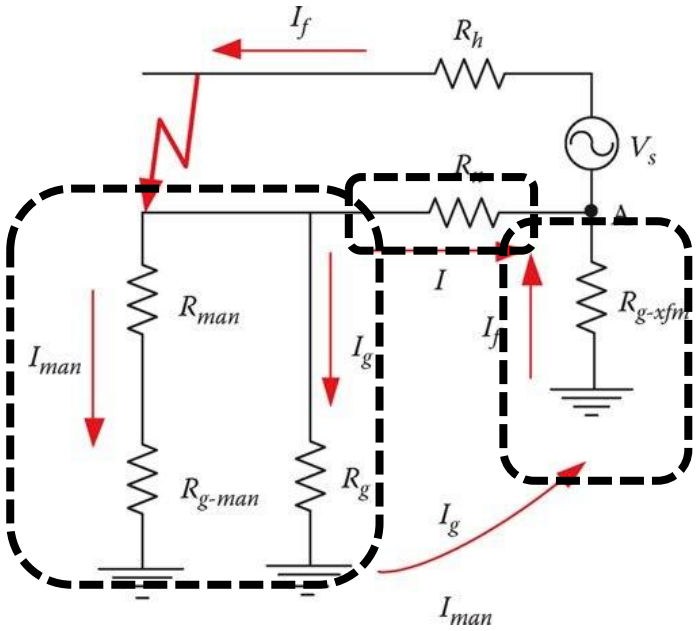


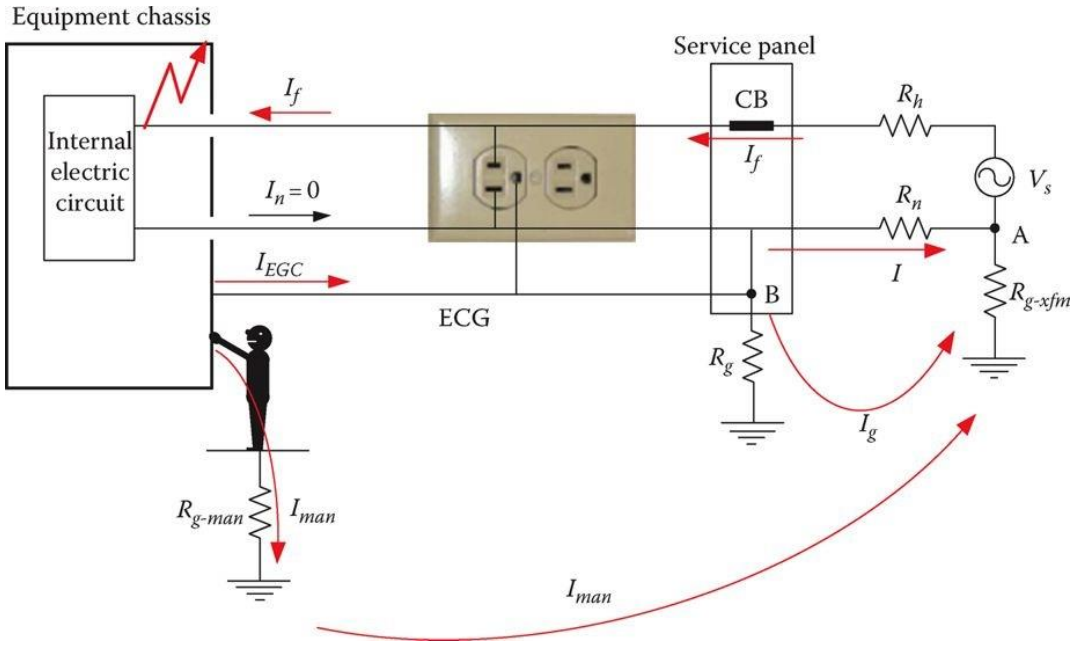
Exercise (Example 9.13)

The fault current is then

$$I_f = \frac{V_s}{R_h + R_{eq}} = 120.97\text{A}$$

This is high enough to trip the circuit breaker



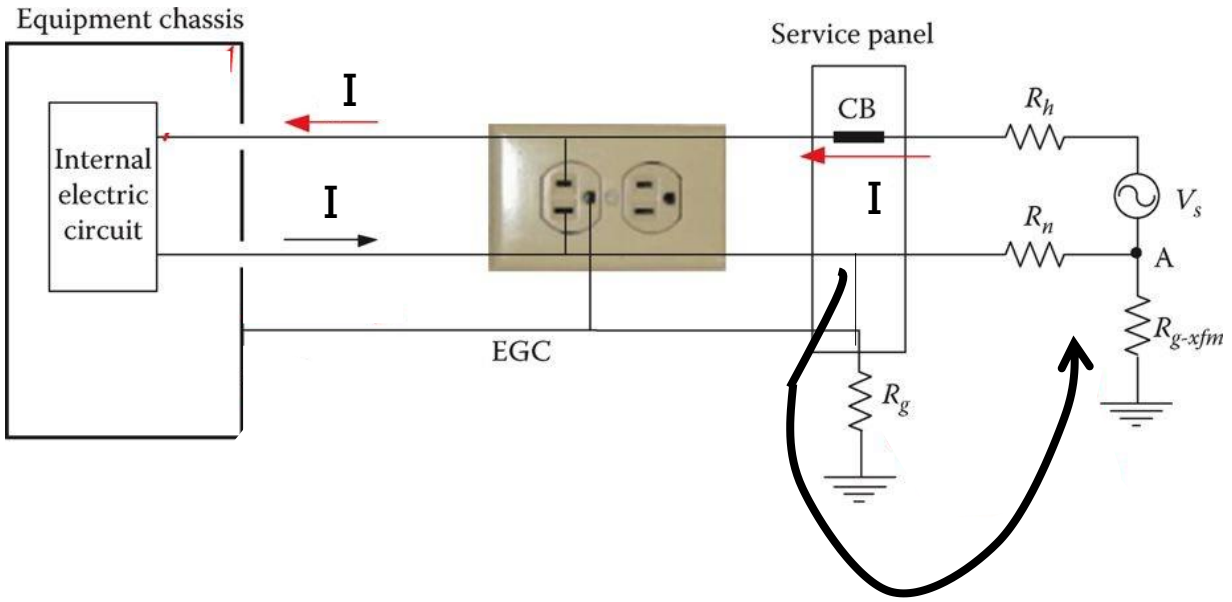


Exercise (Example 9.13)

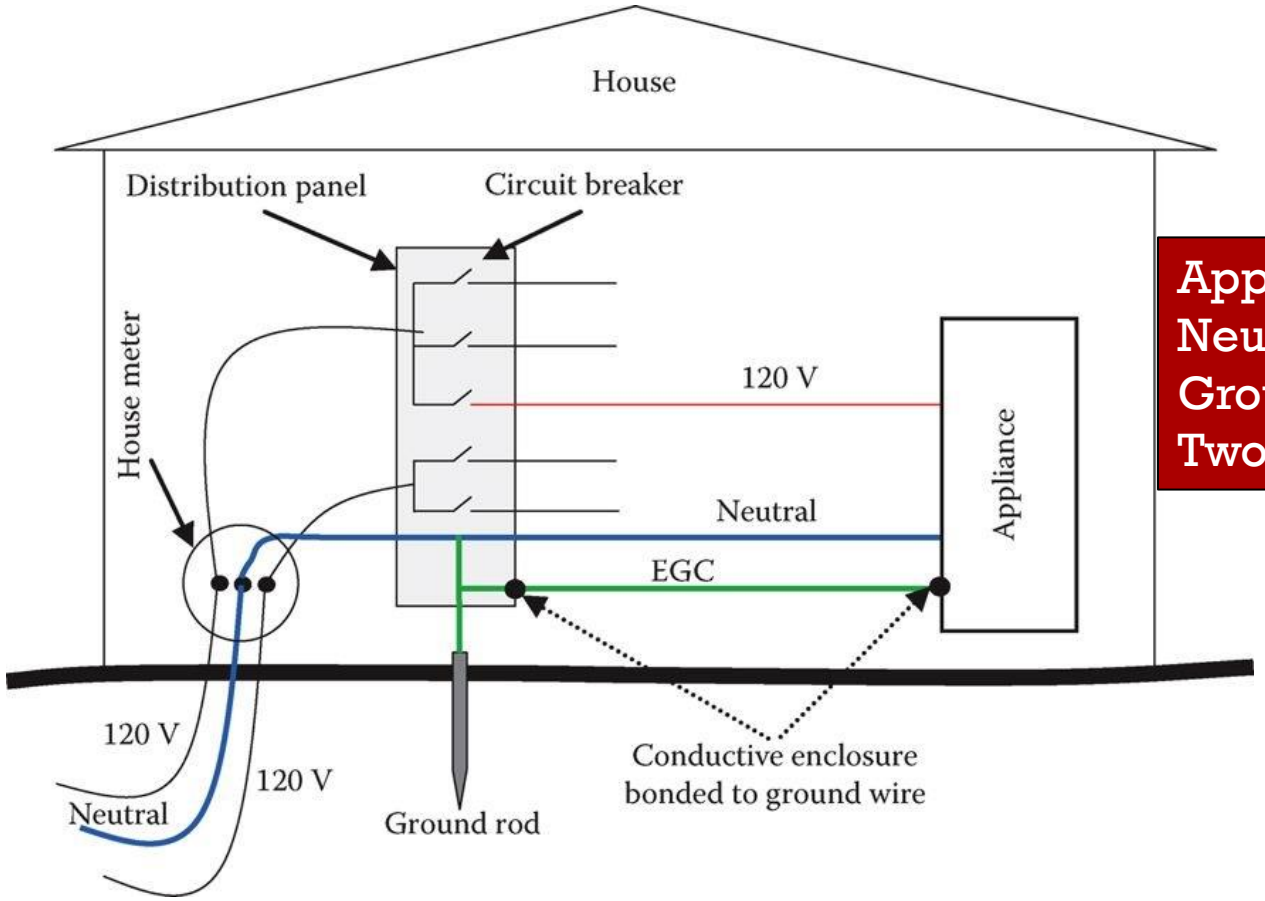
- In the previous example, the current through the person is >10mA (computed by two current dividers)
- However the circuit breaker will trip (and would trip as soon as the internal fault happens—hopefully not at the same time the person touches the appliance!)

Normal Operation

- During normal operation, current flows from appliance back to service panel on the neutral conductor
- Due to the parallel path, some (usually small) current will flow through R_g back to the xfmr through $R_{g\text{-}xmfr}$



Household Distribution System (U.S.)

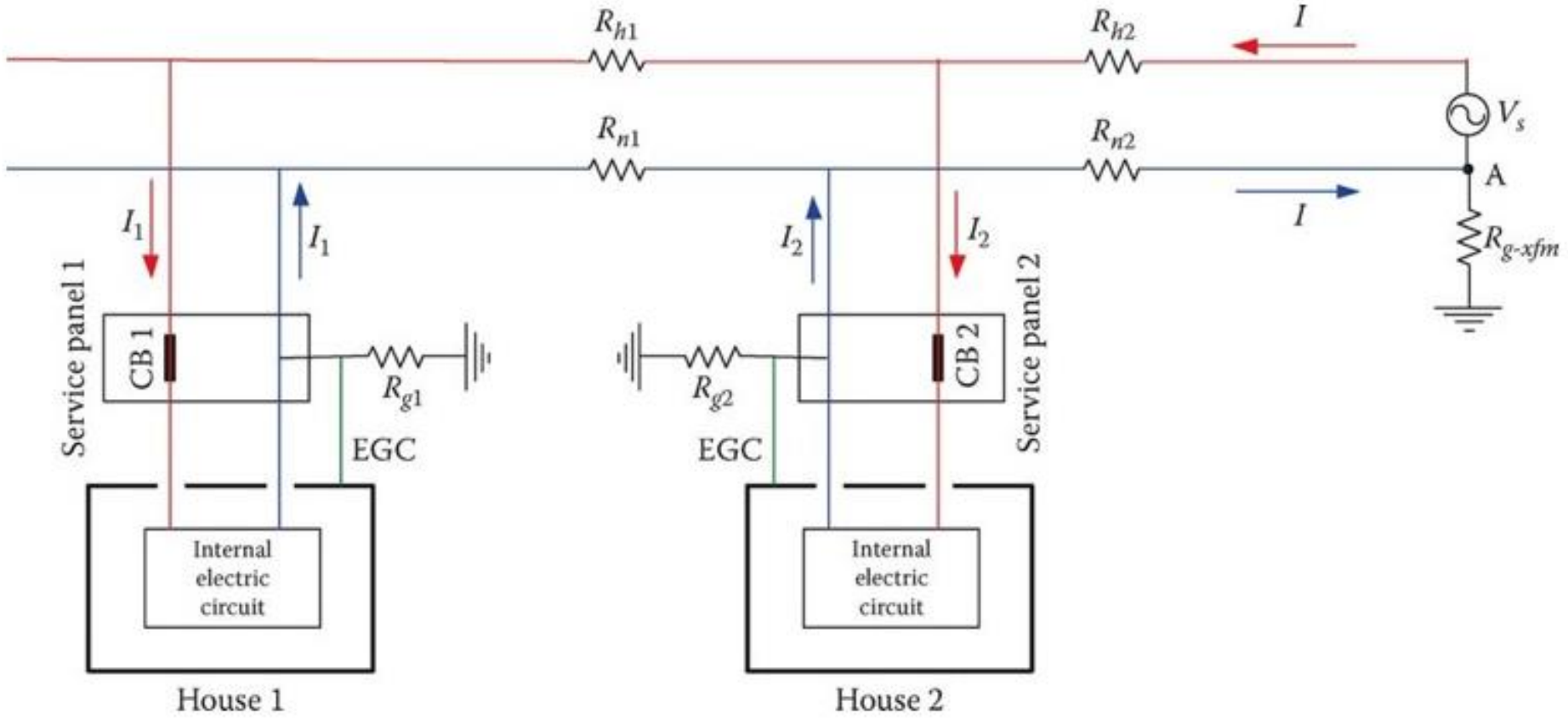


Appliance chassis attached to ground conductor;
Neutral is bonded to ground conductor at service panel;
Ground rod is buried near service panel.
Two hot wires + 1 neutral wire is provided from xmfr

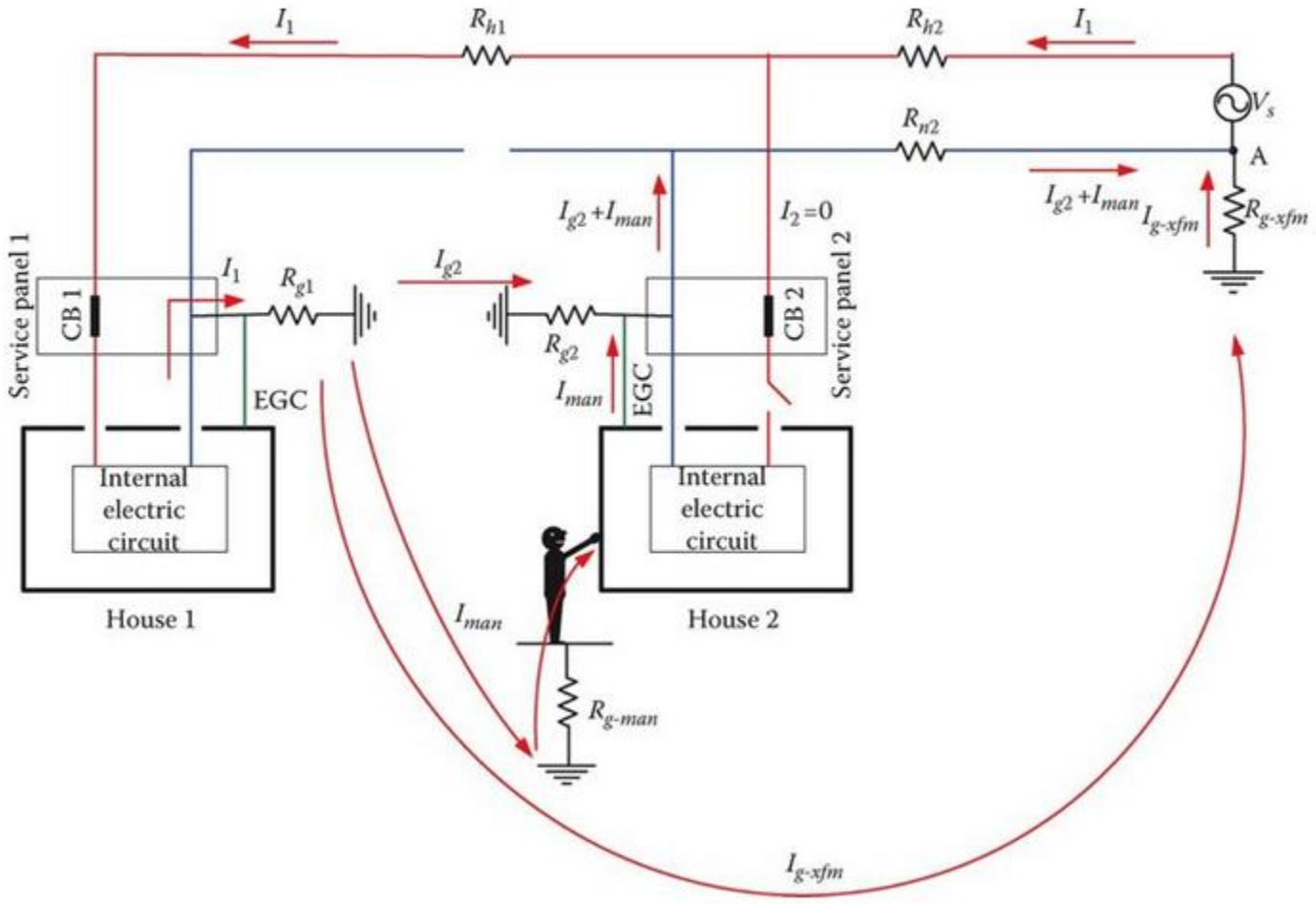
Broken Neutral

- Broken or deteriorated (high impedance) neutrals can cause safety hazards, especially when several homes share an transformer

Two houses served by the same xfmr



With neutral broken

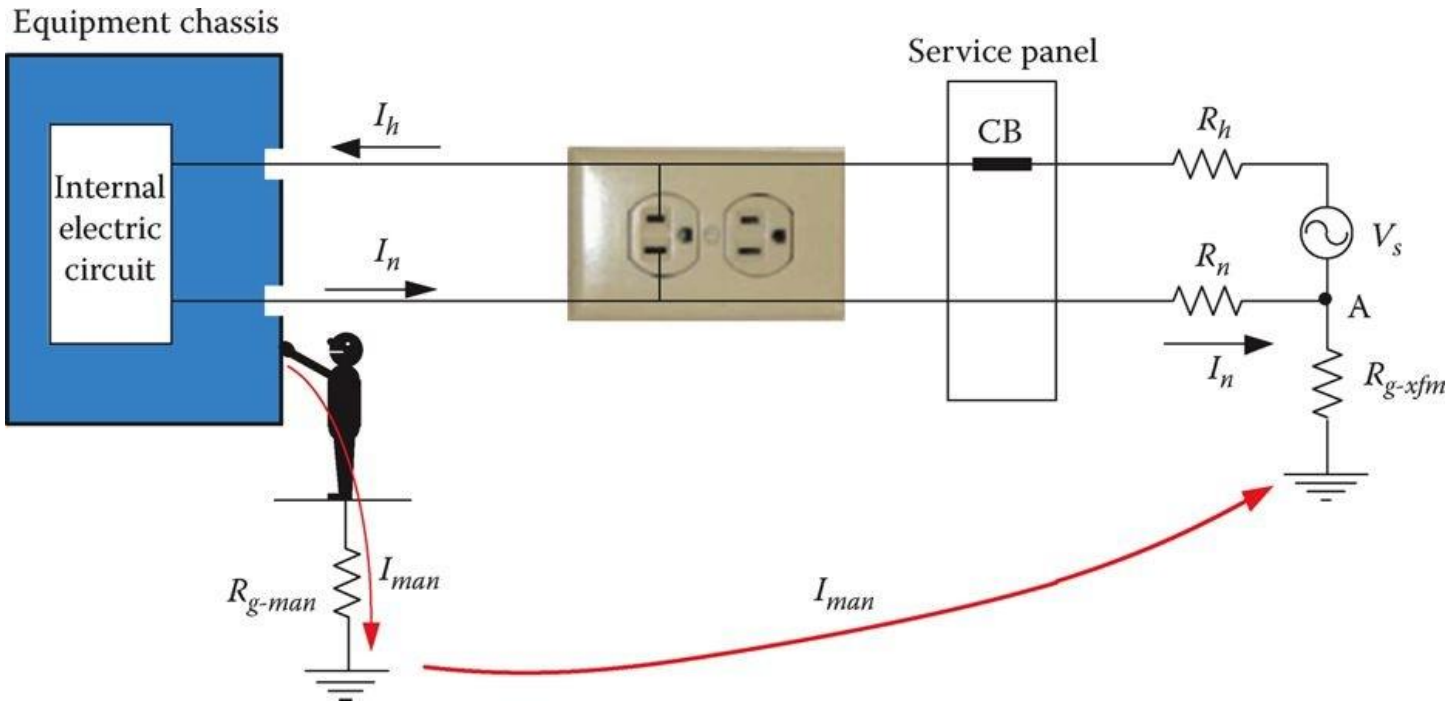


Neutral of House 1 is broken. Current returns through the EGC, and up through the EGC of the Appliance in House 2, causing a shock hazard.

Ground Fault Circuit Interrupter

- GFCI are devices used to protect human life (circuit breakers are design primarily to protect equipment)
- GCFI's are used in high risk areas, for example where there are outlets and water (kitchen, bathroom, outdoors)
- There is also a reasonable chance that the person is wet, and are touching another grounded object (like a part of the plumbing system)

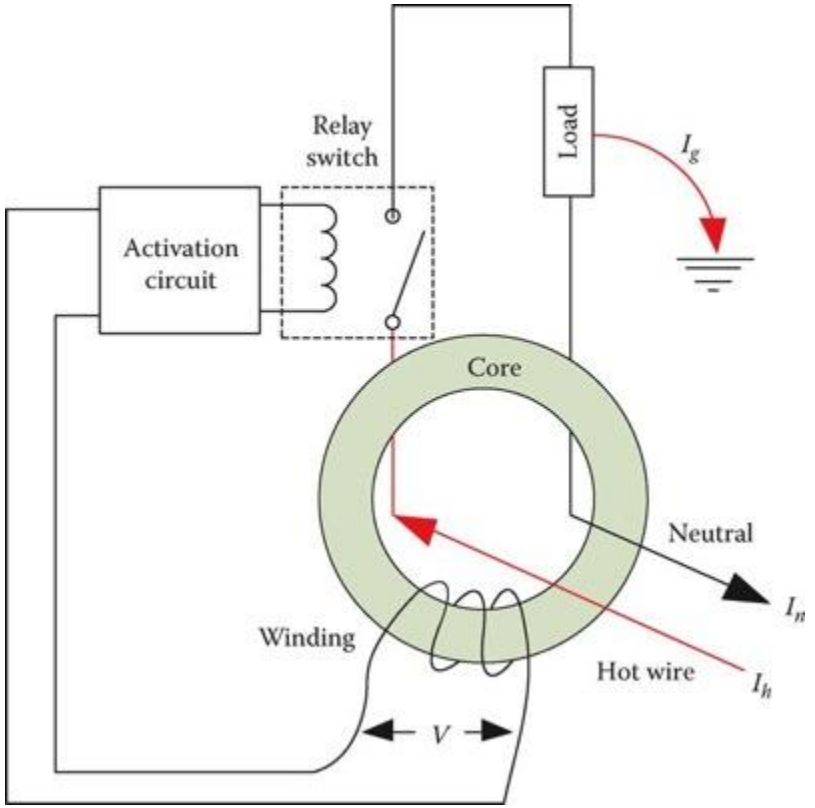
Ground Fault Circuit Interrupter



Ground Fault Circuit Interrupter

- GFCIs work by "counting" the electrons flowing through the hot and "counting" the electrons flowing back on the neutral
- If the two values do not sum to zero at any instant, then there must be a fault to ground
- The GFCI is very sensitive and operates quickly
- Number of house hold consumer product electrocutions dropped dramatically after GFCIs became mandatory

Ground Fault Circuit Interrupter



Read also

- Chapter 9.4.5 (World's Residential Grounding Practices)
- Chapter 9.5 (Low Frequency Magnetic Field and Its Health Effects)